METHOD AND SYSTEM FOR INCREASING RF BANDWIDTH AND BEAMWIDTH IN A COMPACT VOLUME

TECHNICAL FIELD

The present invention is generally directed to an antenna for communicating electromagnetic signals, and relates more particularly to a planar array antenna having patch radiators disposed within a compact volume for increasing RF bandwidth and beamwidth.

BACKGROUND OF THE INVENTION

Antenna designers are often forced to design antennas in a backward fashion. For example, because of the increasing public concern over aesthetics and the "environment", antenna designers are typically required to build an antenna in accordance with a radome that has been approved by the general public, land owners, government organizations, or neighborhood associations that will reside in close proximity to the antenna. Radomes are typically enclosures that protect antennas from environmental conditions such as rain, sleet, snow, dirt, wind, etc. Requiring antenna designers to build an antenna to fit within a radome as opposed to designing or sizing a radome after an antenna is constructed creates many problems for antenna designers. Stated differently, the antenna designer must build an antenna with enhanced functionality within spatial limits that define an antenna volume within a radome. Such a requirement is counterproductive to antenna design since antenna designers recognize that the size of antennas are typically a function of their operating frequency. Therefore, antenna designers need to develop high performance antennas that must fit within volumes that cut against the ability to size antenna structures relative to their operating frequency.

Conventional antenna systems confined within predefined volumes, such as radomes, usually cannot provide for large beamwidths in addition to large bandwidths. In other words, the conventional art typically requires costly and bulky hardware in order to provide for a wide beamwidths and bandwidths, where beamwidth is measured from the half-power points (-3dB to -3dB) of a respective RF

beam. Such bulky and costly hardware usually cannot fit within very small, predefined volumes.

Another drawback of the conventional art relates to the manufacturing of an antenna system and the potential for passive intermodulation (PIM) that can result because of the material used in conventional manufacturing techniques. More specifically, with conventional antenna systems, dissimilar materials, ferrous materials, metal-to-metal contacts, and deformed or soldered junctions are used in order to assemble a respective antenna system. Such manufacturing techniques can make an antenna system more susceptible to PIM and therefore, performance of a conventional antenna system can be substantially reduced.

Accordingly, there is a need in the art for a substantially compact antenna system that can fit within a predefined volume and that can generate relatively wide RF radiation patterns and increased RF bandwidth. Further, there is another need in the art for a compact antenna system that can be manufactured with ease and that can utilize manufacturing techniques which substantially reduce passive intermodulation. There is an additional need in the art for a substantially compact antenna system that can handle the power characteristics of conventional antenna systems without degrading the performance of the antenna system.

SUMMARY OF THE INVENTION

The present invention solves the aforementioned problems with an antenna system that can generate large and wide RF radiation fields in addition to providing increased bandwidth. This enhanced functionality can be achieved with a compact antenna system, where the antenna system without a radome can typically have a height of less than one seventh (1/7) of a wavelength and a width that is less than or equal to six-tenths (0.6) of a wavelength. With an antenna radome, the antenna system can have a height that is less than or equal to one-fifth (1/5) of a wavelength. The antenna system can comprise one or more patch radiators separated from each other by an air dielectric and by relatively small spacer elements. The patch radiators can have predefined shapes for increasing beamwidths.

In one exemplary embodiment, the patch radiators can have a substantially rectangular shape. One or more lower patch radiators can be mounted to a printed

circuit board that can comprise an RF feed network and a ground plane which defines a plurality of symmetrically, shaped slots. In one exemplary embodiment, the slots can comprise a "dog-bone" or "dumbell" shape that has an electrical path length that is less than or equal to a half wavelength.

The slots within the ground plane of the printed circuit board can be excited by stubs that are part of the feed network of the printed circuit board. The slots, in turn, can establish a transverse magnetic mode of RF radiation in a cavity which is disposed adjacent to the ground plane of the printed circuit board and a ground plane of the antenna system.

The cavity can be concentrically aligned with geometric centers of the patch radiators. The feed network of the printed circuit board can be aligned with portions of the cavity such that the portions of the cavity function as a heat sink for absorbing or receiving thermal energy produced by the feed network. Because of this efficient heat transfer function, the printed circuit board can comprise a relatively thin dielectric material that is typically inexpensive.

The cavity disposed between the printed circuit board and the ground plane of the antenna system can function electrically as a closed boundary when mechanically, the cavity has open corners. The open corner design facilitates ease in manufacturing the cavity. The open corners of the cavity can also have dimensions that permit resonance while substantially reducing Passive Intermodulation (PIM).

PIM can be further reduced by planar fasteners used to attach respective flanges and a planar center of a respective cavity to the ground plane of the printed circuit board and the ground plane of the antenna system. The planar fasteners can comprise a dielectric adhesive. In addition to the dielectric adhesive, the present invention can also employ other types of fasteners that reduce the use of dissimilar materials, ferrous materials, metal to metal contacts, deformed or soldered junctions and other similar materials in order to reduce PIM.

For example, the patch radiators can be spaced apart by plastic fasteners that permanently "snap" into place. Such fasteners not only reduce PIM, but also such fasteners substantially reduce labor and material costs associated with the manufacturing of the antenna system.

In one exemplary embodiment, a radome is placed over the patch radiators. Radomes are typically designed to be electrically transparent to the radiators of a antenna system. However, for the present invention, when a radome is placed over the patch radiators, an unexpected result occurs: the performance of the patch radiators is increased. More specifically, return loss is improved and peak gain is higher relative to an antenna without a radome. Further, upper side lobe suppression is improved compared to an antenna without a radome.

While providing a product that can be manufactured efficiently, the present invention also provides an efficient RF antenna system. The RF energy produced by the cavity, slots, and stubs can then be coupled to one or more patch radiators. The patch radiators can then resonate and propagate RF energy with relatively wide beamwidths and increased bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration showing an elevational view of the construction of an exemplary embodiment of the present invention.

Figure 2 is an illustration showing a side view of the exemplary embodiment shown in Figure 1.

Figure 3 is an illustration showing an isometric view of the exemplary embodiment shown in Figures 1 and 2.

Figure 4 is a cross-sectional view of the exemplary embodiment illustrated in Figure 3 taken along the cut line 4-4.

Figure 5 is a block diagram illustrating some of the core components of the exemplary embodiment illustrated in Figure 5.

Figure 6 is an illustration showing an elevational view of the exemplary embodiment illustrated in Figure 4 while also showing hidden views of the slots which feed the cavity and one or more radiating elements.

Figure 7 is an illustration showing an exemplary slot according to the present invention.

Figure 8 is an illustration showing an exploded view of an exemplary embodiment of the present invention.

Figure 9A illustrates an elevation polar radiation pattern for an exemplary embodiment that employs radome.

Figure 9B illlustrates an elevation polar radiation pattern for an exemplary embodiment that does not employ a radome.

Figure 9C illustrates an azimuth polar radiation pattern for an exemplary embodiment that employs radome.

Figure 9D illlustrates an azimuth polar radiation pattern for an exemplary embodiment that does not employ a radome.

Figure 9E is an illustration showing a bottom or rear view of a ground plane of the printed circuit board comprising the feed network as illustrated in Figure 8.

Figure 10A is an illustration showing an isometric view of an exemplary resonant cavity for the present invention.

Figure 10B is an illustration showing an enlarged area focused on an exemplary corner structure of the resonant cavity shown in Figure 10A.

Figure 11 is an illustration showing a typical mounting arrangement for an antenna provided by an exemplary embodiment of the present invention.

Figure 12 is an exemplary logical flow diagram highlighting exemplary steps of a method for increasing RF beamwidth and bandwidth in a compact volume.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

The antenna of the present invention can solve the aforementioned problems and is useful for wireless communications applications, such as personal communication services (PCS) and cellular mobile radio telephone (CMR) service. The antenna system can include one or more patch radiators, a printed circuit board disposed adjacent to the one or more patch radiators, and plurality of slots disposed within a ground plane of the printed circuit board. The antenna further includes a cavity disposed adjacent to the ground plane of the printed circuit board and a second ground plane disposed adjacent to the cavity. The antenna system radiates RF energy with relatively wide beamwidth and bandwidth.

Turning now to the drawings, in which like reference numerals refer to like elements, Figure 1 is an illustration showing an elevational view of one exemplary embodiment of the present invention. Referring now to Figure 1, an antenna system

100 is shown for communicating electromagnetic signals with the high frequency spectrums associated with conventional wireless communication systems. An antenna system **100** can be implemented as a planar array of radiating elements **110, 140** known as wave generators or radiators, wherein the array is positioned along a vertical plane of the antenna as viewed normal to the antenna site.

The antenna system **100**, which can transmit and receive electromagnetic signals, includes radiating elements **110, 140**, a ground plane **120**, and a feed network **130**. The antenna system **100** further includes a printed circuit board **150**, and a port **160**.

Referring now to Figure 2 which illustrates the side view of the antenna system **100** of Figure 1, the spatial relationship between a first set of radiating elements **110** and a second set of radiating elements **140** are more clearly shown. The first set of radiating elements **110** are positioned between the second set of radiating elements **140** and the printed circuit board **150**. On a side of the printed circuit board **150** opposite to the first set of radiating elements **110** and the second set of radiating elements **140** are a plurality of cavities **200** which will be discussed in further detail below. The port **160** can comprise a coaxial cable type connector.

Figure 3 further illustrates an isometric view of the antenna system **100** which can comprise a plurality of a first set of radiating elements **110** and a second set of radiating elements **140**. The antenna system **100** as illustrated in Figure 3 is very compact yet high performance product that can be placed or positioned in a very narrow or small volume such as a radome. For example, in one exemplary embodiment, the length L can be approximately 72 inches while the width W can be approximately 8 inches. The height H of the antenna system **100** (including a radome) can be 2.75 inches. In this exemplary embodiment the operating frequency range is approximately from 806 MHz to 896 MHz. In terms of wavelength, this means that the width W can be less than or equal to six-tenths (0.6) of a wavelength. Similarly, the height H, without a radome, can be less than or equal to one-seventh (1/7) of a wavelength. The height H, with a radome, can be less than or equal to one-fifth (1/5) of a wavelength. ~~The length L can be~~ varied depending upon the number of radiating elements **110** desired to be in the antenna system **100**.

Referring now to Figure 4, this figure illustrates a cross-section of the antenna system **100** illustrated in Figure 3. This particular cross-section is taken along the cut line 4-4 as illustrated in Figure 3. Figure 4 provides further details of the mechanical elements which form the inventive antenna system **100**. The sizes of materials illustrated in Figure 5 are not shown to scale. In other words, some of the materials have been exaggerated in size so that these materials can be seen easily. A more accurate depiction of the relative sizes of materials will be illustrated below with respect to Figure 11.

A second radiating element **140** is spaced from a first radiating element **110** by a spacing S1. Spacing S1 is typically a resonant dimension. That is, the parameter S1 size is typically a resonant dimension or a dimension that promotes resonance of the second radiating element **140**. The second radiating element **140** in one exemplary embodiment can have a length L1 of 0.364 wavelengths and a width W1 of 0.144 wavelengths. However, the present invention is not limited to these values. Other resonant dimensions are not beyond the scope of the present invention. Further, the present invention is not limited to a plurality of radiating elements **110, 140**. A single radiating element can be employed with out departing from the scope and spirit of the invention.

The first radiating antenna element **110** can be spaced from the printed circuit board **150** by a spacing parameter S2 which is also typically a resonant value. In other words, the parameter S2 is one that typically promotes resonance of the radiating patch element **110**. In terms of wavelength, the parameter S2 is typically between 0.03 to 0.05 wavelengths (or 0.42 to 0.83 inches at the exemplary operating frequency range). The first radiating element **110** in one exemplary embodiment can have a length L2 of 0.364 wavelengths and a width W2 of 0.224 wavelengths. However, the present invention is not limited to these values. Other resonant dimensions are not beyond the scope of the present invention.

The second radiating element **140** is typically held in place relative to the first radiating element **110** by spacer elements/fasteners **500** which can comprise dielectric stand-offs. The first radiating element **110** is similarly positioned from the printed circuit board **150** by a plurality of spacers/fasteners **500**. The spacers/fasteners **500** are typically designed to permanently "snap" into place in order to eliminate or reduce

the use of soldering points of the present invention. This, in turn, also substantially reduces work in the manufacturing process of the Antenna System **100**. Further, by using such spacers/fasteners passive intermodulation (PIM) can also be substantially reduced or eliminated. However, the present invention is not limited to "snap" type fasteners. Other fasteners or dielectric supports that can reduce PIM are not beyond the scope of the present invention. For example, slim or narrow blocks of dielectric foams could be used to support the radiating elements **110, 140**.

As illustrated in Figures 3 and 4, the second radiating element **140** and the first radiating element **110** typically comprise patch elements. The second radiating element **140** and first radiating element **110** are typically made from conductive materials such as aluminum. Specifically, both elements can be made from aluminum 5052. Similarly, the cavity **200** can also be constructed from aluminum. However, other conductive materials are not beyond the scope of the present invention for the radiating structures. Further, the radiating elements **110, 140** can also be constructed with combinations of materials such as dielectric materials coated with a metal. Those skilled in the art will appreciate the various ways in which radiating elements can be constructed without departing from the scope and spirit of the present invention.

In one preferred exemplary embodiment, both the second radiating element **140** and first radiating element **110** are substantially rectangular in shape. The rectangular shape of the patches **140, 110** in combination with the apertures or slots **700** (as will be discussed below) and resonating cavity **200** increase bandwidth and beamwidth produced by the antenna system **100**. However, the present invention is not limited to rectangular shaped patch elements. Other shapes include, but are not limited to, square, circular, and other similar shapes that maximize the beamwidth and bandwidth of a compact antenna system.

The present invention is also not limited to the number of radiating elements **110, 140** within a stacked arrangement or the number of stacked arrangements illustrated in the drawings. Additional or fewer radiating elements **110, 140** of stacked arrangements are not beyond the scope of the present invention. For example, more radiating elements **110, 140** could be employed in respective stacked arrangements in order to increase bandwidth.

Figure 4 illustrates further details of the antenna system **100** that are not shown in the previous figures. For example, portions of the feed network **130** are substantially aligned over portions of the cavity **200**. By aligning portions of the feed network **130** over portions of the cavity **200**, such as flanges **520** (as will be discussed in further detail below) the present invention can dissipate heat energy formed within the feed network **130** more efficiently and rapidly. The flanges **520** can serve as a heat sink to portions of the feed network **130**.

By using portions of the resonating **200** cavity as a heat sink, a relatively thin printed circuit board **150** can be used. The cavity **200** can be fastened to the printed circuit board **150** (and more specifically, the ground plane **530** of the printed circuit board **150**) by using a planar fastener **540** such as a dielectric adhesive. This planar fastener **540** can then reduce the thermal resistance between the feed network **130** and the flange **520**.

The cavity **200** can also be attached to the ground plane **120** with a similar planar fastener **540** such as a dielectric adhesive discussed above. Using such fasteners not only reduces the thermal resistance between the feed network **130** and the cavity, it also substantially reduces passive intermodulation (PIM). With portions of the cavity **200** functioning as a heat sink for the feed network **130** exposed upon a printed circuit board **150**, a relatively thin substrate of material can be used as the printed circuit board **150**. The cavity **200** is attached to the ground plane **530** of the printed circuit board **150** with a planar fastener **540**. Similarly, the cavity **200** is attached to the radome supporting ground plane **120** by a planar fastener **540**.

The cavity **200** typically propagates a single transverse magnetic (TM_{01}) mode of RF energy for the single polarization supported by the antenna system **100**. Since cavity **200** resonates, the height or spacing S3 of the cavity has a resonant dimension of 0.027 wavelengths (or a dimension of 0.375 inches at the exemplary operating frequency). The length L3 and width W3 of the resonant cavity **200** each can have a resonant dimension of 0.433 wavelengths. However, the present invention is not limited to these values. Other resonant dimensions are ~~not beyond the scope of the~~ present invention. While propagating a transverse magnetic ~~mode of RF energy,~~ cavity **200** can also substantially increase the front to back ratio of the antenna system

100. The cavity **200** is excited by a slot **700** as will be discussed in further detail below.

Figure 5 is a functional block diagram illustrating the various components which make up the compact antenna system **100**. This figure highlights one exemplary and preferred arrangement of the components of the antenna system **100**. Of the components illustrated in Figure 6, there are a select few which may be considered the core components of the Antenna System **100** that provide the enhanced functionality in such a compact antenna volume. The core components may be considered as the second radiating element **140**, the first radiating element **110**, the printed circuit board **150**, the ground plane **530** with slots **700**, and the cavity **200**.

Referring now to Figure 6, further details of the slots **700** disposed within the ground plane **530** are shown. The slots **700** are excited by pairs of stubs **710** that are positioned within the feed network **130** disposed on one side of the printed circuit board **150**. The spacing and orientation of the slots **700** relative to the first radiating element **110** can optimize the desired transverse magnetic TM_{01} mode of operation within the resonating cavity **200**. Optimization of the TM_{01} mode of operation can also be accomplished by using the center of the cavity **200** as the origin for the radiating patches **110, 140**. That is, the geometric centers of the patch radiators **110, 140** and cavities **200** can be concentrically aligned.

Referring now to Figure 7, the slots **700** can also have a predefined shape. For example, in one exemplary embodiment, each slot **700** have a "dogbone" or "dumbell" shape. Typically, this shape comprises two circular regions spaced apart by a relatively long, linear region. However, the present invention is not limited to this shape. Other shapes include, but are not limited to, H-shapes, rectangular shapes, and other shapes that have an electrical length that is less than or equal to one-half the wavelength. The electrical length of a slot is typically found by measuring half of the perimeter of the opening, starting at one far end of the slot to another far end. An electrical length of less than or equal to one-half of a wavelength facilitates efficient coupling of RF energy to the cavity **200** and patch first radiating element **110**. Also, the present invention is not limited to a single slot embodiment where two stubs **710** feed a slot. For example, pairs of slots could be matched with pairs of stubs **710**.

That is, each stub **710** could feed a respective slot **700**. Other combinations of slots and stubs are not beyond the scope of the present invention.

Referring now to Figure 8, this figure illustrates an exploded view of the components of the antenna system **100**. A protective radome **800** comprising a PVC material can be used to cover the antenna system **100**. A radome **800** preferably comprises a PVC material manufactured in the desired form by an extrusion process. The radome **800** is attached to the grooves **400** formed in the ground plane **120**. A pair of end caps **810A** and **810B** are positioned along a minor dimension at an end of the ground plane **120** and cover the remaining openings formed at the end of the combination of the ground plane **120** and the radome **800**. Encapsulation of the antenna system **100** within the sealed enclosure formed by the ground plane **120**, a radome **800**, and the end caps **810A-B** protects the antenna system **100** from environmental elements, such as direct sunlight, water, dust, dirt and moisture.

In the exemplary embodiment illustrated in Figure 8, each of the cavities **200** have an aperture **820** disposed in the base portion. This aperture **820** is designed to receive a portion of a mounting bracket **830**. However, typically only two mounting brackets **830** are employed for an antenna array. But each cavity **200** may include an aperture **820** to facilitate repeatability in manufacturing and sharing of parts. For those cavities **200** in an array that do not receive the mounting bracket **830**, the apertures **820** are electrically and mechanically closed by the ground plane **120**. During antenna operation, due to the thickness of a respective cavity **200** and the thickness of a respective planar fastener **540**, an aperture **820** not receiving a mounting bracket **830** is virtually electrically transparent.

When radome **800** is positioned over the radiating elements **110, 140,** performance of the antenna system **100** is unexpectedly enhanced. In other words, while radomes are usually designed to be transparent and to have little or no effect on RF energy being generated or received by an antenna, radome **800** provides for some unexpected results for the present invention. More specifically, Table 1 illustrates some increased performance in peak gain, upper side lobe suppression, and in return loss when radome **800** is encloses ~~the inventive~~ antenna.

Table 1 - Enhanced Performance of Antenna with Radome

		806 MHz	828.5 MHz	851 MHz	873.5 MHz	896 MHz	Average
Peak Gain (dBd)	**With radome**	11.34	11.51	11.5	11.58	11.79	11.54
	W/o radome	11	11.49	11.45	11.26	11.53	11.34
USS* (dB)	**With radome**	20	17.5	23	26	25	22.3
	W/o radome	18	16	11.5	22.5	20.5	17.7
Return Loss (dB)	**With radome**	-18.1	-24	-20.6	-22	-20.9	-21.1
	W/o radome	-14.8	-20.5	-17.7	-17	-17.9	-17.6

Figure 9A illustrates an elevation polar radiation pattern for an exemplary embodiment that employs radome **800** when the antenna array is aligned in a vertical position. Reference numeral **905** denotes an exemplary region of upper side lobe suppression improvement. Figure 9B illlustrates an elevation polar radiation pattern for an exemplary embodiment that does not employ a radome **800** when the antenna array is aligned in a vertical position.

Figure 9C illustrates an azimuth polar radiation pattern for an exemplary embodiment that employs radome **800** when the antenna array is aligned in a vertical position. Figure 9D illlustrates an azimuth polar radiation pattern for an exemplary embodiment that does not employ a radome **800** when the antenna array is aligned in a vertical position.

The printed circuit board **150** is a relatively thin sheet of dielectric material and can be one of many low-loss dielectric materials used for the purpose of radio circuitry. In one preferred and exemplary embodiment, the material used has a relative dielectric constant value of $d_k = 3.38$ (and $\varepsilon_r = 2.7$ - when substrate is used as microstrip). In the preferred exemplary environment, TEFLON-based substrate materials are typically not used in order reduce cost. However, TEFLON-based substrate materials and other dielectric materials are not beyond the scope of the

Referring now to Figure 9E, the ground plane **530** contains the slots **700** used to excite the cavity **200**. These slots **700** can be preferably etched out of the ground plane **530** by photolithography techniques.

Referring now to Figure 10A, this figure further illustrates the details of the resonant cavity **200**. The cavity **200** is preferably made from aluminum and has a design which promotes accurate repeatability while substantially reducing passive intermodulation (PIM). However, other conductive materials are not beyond the scope of the present invention. The cavity **200** comprises walls **1000A-D** that are spaced apart from each other by a predetermined distance d (See Figure 10B). This predetermined distance d between the walls **1000** at the corners allows for reasonable tolerances in manufacturing, but is typically small enough such that the cavity **200** electrically operates as a closed boundary for RF energy propagating within the cavity **200**. In other words, the cavity **200** can function electrically as a closed boundary when mechanically the cavity has open corners. The open corners of the cavity typically have dimensions that permit resonance while substantially reducing passive intermodulation (PIM). The open corners of the cavity also function as drainage holes for any condensation that may form within a respective cavity **200**.

Referring now to Figure 10B, a distance d exists between cavity walls **1000C** and **1000D**. As mentioned above, distance d is sized such that the cavity can resonate while at the same time it can substantially reduce passive intermodulation since there is no metal-to-metal contact between the respective walls **1000C** and **1000D**. PIM is further reduced by the present invention because dissimilar materials, ferrous materials, metal-to-metal contacts, and deformed or soldered junctions are preferably not used in order to substantially reduce or eliminate this physical phenomenon.

For example, in addition to the open corners of the cavity **200**, the present invention employs (as discussed above) planar fasteners **540** to attach the Flanges **520** of the cavity **200** to the ground plane **530** of the printed circuit board **120**. Meanwhile, the base of the cavity **200** can be attached to the radome-supporting ground plane **120** by another dielectric planar fastener. Similarly, the first radiating element **110** is supported by non-soldered spacers/fasteners **500**, and also supports additional spacers/fasteners **500** to support the second radiating element **140**.

Referring now to Figure 11, this figure further illustrates a more accurate depiction of the relative sizes (thickness) of materials which make up the antenna system **100**. Further mechanical details of the spacers/fasteners **500** are shown. As mentioned previously, these spacers/fasteners are preferably constructed from dielectric materials to reduce (PIM) while also permitting ease of manufacturing of the antenna system **100**. That is, the spacers/fasteners **500** can be permanently "snapped" into place without the use of any deformed or soldered junctions.

Figure 12 illustrates a logical flow diagram **1200** for a method increasing RF bandwidth and beamwidth within a compact volume. The logical flow diagram **1200** highlights some key functions of the antenna system **100**.

Step **1210** is the first step of the inventive process **1200** in which the antenna system **100** is assembled without metal-to-metal contacts and soldering. More specifically, in this step, the antenna system **100** can be manufactured in a way to substantially reduce passive intermodulation (PIM). Dissimilar materials, ferrous materials, metal-to-metal contacts, and deformed or soldered junctions are typically not employed or are limited in the antenna system **100** in order to substantially reduce or eliminate PIM. One way in which PIM is substantially reduced or eliminated is the use of dielectric planar fasteners **540** in order to connect portions of the cavity **200** to the slotted ground plane **530** and the ground plane **120**. Another way in which PIM is reduced or substantially eliminated is by employing open corners in the cavity **200** where respective walls, such as walls **1000C** and **1000D** of Figure 10B, are spaced apart by the predetermined distance d.

Next, in step **1220** RF energy is propagated along the feed network **130** of the printed circuit board **150**. In step **1230**, heat is dissipated from the feed network **130** into flanges **520** of the cavity **200**.

In step **1240**, the slots **700** are symmetrically shaped and sized such that each slot has an effective electrical length of less than or equal to a half wavelength. Such shape and size of the slots **700** promotes efficient RF coupling between the slots **700** and the stubs **710** and between the slots **700** and the resonant cavities **200**.

In step **1250**, the slots **700** disposed in ground plane **530** set up or establish a transverse magnetic (TM) mode of RF energy in the cavity **200**. Next, in step **1260**, the radiating elements such as the first and second patch radiators **110, 140** are excited

with RF energy emitted from the slot **700** or the stubs **710** or both. Next, in step **1270**, RF radiation is produced with increased RF beamwidth and bandwidth.

The present invention provides cavity-backed, aperture or slot coupled patch elements that produce RF energy with increased beamwidths and bandwidths. The present invention also provides a compact antenna system that has a height (without a radome) of less than one seventh (1/7) of a wavelength and a width that is less than or equal to six-tenths (0.6) of a wavelength. With a radome, the height can be one-fifth (1/5) of a wavelength. While being compact, the present invention is power efficient. The present invention incorporates an efficient heat transfer design such that a feed network transfers its heat to a resonating cavity used to set up desired transverse magnetic modes of RF energy. The efficient heat transfer permits the present invention to utilize relatively thin dielectric materials for the printed circuit board supporting the feed network.

The present invention further incorporates a low PIM design approach by utilizing capacitive coupling of all potential metal-to-metal junctions through employing non-conductive planar fasteners and open corners for the resonant cavity **200**. The low PIM design approach also yields efficient and low cost manufacturing methods. For example, the planar fasteners **540** eliminate any need for soldering the resonant cavity **200** to the ground plane **530**. The use of dielectric spacers **500** further eliminates any need for costly dielectric spacer sheets while also reducing assembly time.

The radome **800** yields some unexpected results for the present invention. While designed to be electrically transparent to the radiating elements **110, 140**, the radome **800** actually increases the performance of the antenna system **100**.

Alternative embodiments will become apparent to those skilled in the art to which the present invention pertains without departing from its spirit and scope. Thus, although this invention has been described in exemplary form with a certain degree of particularity, it should be understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and scope of the invention. Accordingly, the scope of the present invention is defined by the appended claims rather than the foregoing description.